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SUMMARY

An experimental investigation was conducted to assess the effects of noise frequency on both task performance and annoyance. For the experiment, 30 females and 30 males served as subjects. The study consisted of tests involving a complex psychomotor task which was performed in the presence of: (1) low-frequency noise, 90 dB SPL; (2) high-frequency noise, 90 dB SPL; or (3) ambient noise, 55 dB SPL. Subsequent to an initial practice session, each subject performed the task for 50 minutes under one of the randomly assigned experimental conditions. Then annoyance ratings were obtained for noises of various frequencies through the method of magnitude estimation. The results of the present study suggest that high-frequency noise affects female performance to a greater extent than male performance. However, the possible confounding effects of learning and of sex differences in ambient conditions make these results tentative. Contrasted to these performance effects, the sexes did not differ in their annoyance ratings. Thus, the implication was derived that there is not a simple transformation between performance and annoyance responses. A monotonically increasing relationship between annoyance and noise frequency was found (except for a decrease in annoyance at 8,000 Hz). Therefore, it is concluded that both performance and annoyance responses may need to be assessed in certain situations to adequately describe human reaction to noise.

INTRODUCTION

The influence of noise on man has been measured through diverse physiological, performance, and affective-type response measures (ref. 1). Relative to the effect of noise on performance, a recent literature review (ref. 2) has indicated that noise which is high frequency ($\geq 2,000$ Hz), high intensity (≥ 90 dB), random, and intermittent in nature, generally has a detrimental effect on task performance. These same noise characteristics have been found in part to determine the affective response of annoyance to noise (refs. 1 and 3). An extension of this reasoning leads to the question of whether or not very low, yet audible frequencies such as those often found in industrial settings, produce performance and annoyance reactions similar to those of high frequencies, and if these performance and annoyance response measures are related. Furthermore, it is of interest to determine if these response measures vary between females and males.

Therefore, the purposes of the present experiment were: (1) to investigate the effects of high- and low-frequency noise on complex psychomotor task performance; (2) to assess the effects of noise frequency on annoyance ratings; (3) to examine the relationship between performance and annoyance response for these noise conditions; and (4) to determine if these performance and annoyance responses vary according to sex of the person.

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METHOD

This experiment was divided into two parts. The first part was directed at assessment of the effects of noise on performance whereas the second part addressed the effects of noise on annoyance. The methodologies associated with each part of the experiment are discussed in sections subsequent to a description of the subjects who were common to each part of the investigation.

Subjects

A total of 60 college students (30 female and 30 male, ages 18 to 30 years old) volunteered to be subjects in the study. Experimental course credit and an opportunity to win one of three small cash prizes were received for participation. Five subjects failed to be present for the second session and were replaced.

Performance Tests

Noise exposure.- Three different noise conditions were presented to the subjects during the performance tests. These were:

- (1) High-frequency noise consisting of a recording of a sabre saw filtered to a broadband noise in the frequency range of 2 to 20 kHz (dominant bands were 2.5, 3.15, and 8.0 kHz) adjusted to 90 dB SPL overall (re. 2×10^{-5} N/m²).
- (2) Low-frequency noise consisting of a recording of a large industrial air compressor filtered to a 1/3-octave band centered at 125 Hz adjusted to 90 dB SPL.
- (3) Ambient noise of approximately 55 dB SPL.

The first two conditions were presented via audiometric headphones as random, intermittent with a 40 percent ontime ratio for a total time period varying between 25 to 45 minutes (time varied for subjects to complete performance task). The noise stimulus was approximately 2 seconds in duration. Offtime varied randomly between 2 to 7 seconds. During the ambient condition, subjects wore inoperative headphones as an experimental control for any effect due to wearing headphones. The frequency response of the headphones was flat to 8,000 Hz where it sharply dropped 12 dB.

Performance task apparatus.- Performance was measured with the NASA Langley Complex Coordinator which is illustrated in figure 1. The coordinator rests at approximately eye level, 0.71 m from the subject, and is composed of four sets of lights. Each set consists of five pairs of colored lights and is associated with a limb of the body. The left lights in each set give the problem and are referred to as "problem lights." The lights on the right in each set are activated through movements of hand sticks by each hand and floor pedals by each foot. When the problem lights are activated, the subject moves the coordinator controls, the sticks and pedals, until the "moving lights" (the lights on the right) are aligned with each problem light. When the correct answer is made for each set of lights and held for 0.25 seconds, a new problem automatically appears. There are a total of 50 problems within a period termed a trial. The experimenter's controls for the coordinator are located in a separate room from that used by the subject.

Design.- The basic design shown in Table I was used to analyze both time and error aspects of performance. These measures were defined as the time to complete a trial, and as the number of overshoots per trial, respectively. The design is a 3 x 2 x 6 split plot factorial with 10 subjects per cell. The

two between group variables were noise characteristics (high frequency, low frequency, and ambient) and sex. The within group variable was trials, of which there were six, each containing 50 problems. Subjects within each sex group were randomly assigned to one of the three noise conditions upon arrival at the laboratory.

Procedure.- A noise exposure history, medical history, hearing test (consisting of the low- and high-frequency noises used in the study), and health condition were obtained from each subject upon arrival at the laboratory. In order to participate, subjects had to meet specific criteria in each of those areas. Subsequent to these tests, each subject was shown the complex coordinator and was told that this was an experiment on performance, but that noise may be heard from time to time. The instructions given each subject are reproduced in Appendix A.

The performance assessment was divided into two sessions. For the first session, the practice session, the subject was given six trials with a 90 second intertrial interval. No noise was presented. The purpose of this session was to establish a baseline. Two days later, the subject returned to the laboratory and was given one practice trial. After a 90 second pause, the test condition began. For any experimental condition, six trials, with a 90 second intertrial interval were presented. During both sessions the subjects wore headphones. Upon completion of the second performance session, annoyance ratings were obtained as described in the following sections.

Annoyance Ratings

Noise exposure.- One-third octave bands of pink noise (with center frequencies of 63, 125, 250, 500, 1,000, 2,000, 4,000, and 8,000 Hz) as well

as samples of the low-frequency noise and of the high-frequency noise (used in the performance tests) were presented to subjects for magnitude estimations of annoyance. All noises were 90 dB SPL. A 1/3-octave band centered at 1,000 Hz was used as a standard. Each noise was 2 seconds in duration with a 5 second offtime between pairs of noises (standard and test noises). The noises were recorded and presented via tape recorder and audiometric headphones.

Design.- The 10 noises were randomized (without replacement) for presentation to a subject. Three such randomizations were presented to a subject. Different randomizations were used for different subjects.

Procedure.- Subsequent to the performance tests, described in previous sections, each subject was provided instructions for the magnitude estimation procedure which was used to evaluate the annoyance of noises. The exact instructions given to the subjects are presented in Appendix B.

RESULTS AND DISCUSSION

The results of the performance and annoyance testing are described in the following two sections. A third section provides information for comparison of these responses.

Performance Responses

In order to summarize the performance data, analyses of variance with repeated measures were computed separately for the error and the time data. No significant effects were found for the error measure, therefore, this measure is not discussed further. For the time measure, the main effect for sex as well as several interactions were significant as shown in Table II. The importance of these significant effects are discussed in successive subsections

Noise effects.- In general, performance was worse for subjects in either the high- or low-frequency conditions compared to those in the ambient conditions as shown in figure 2. The decrements for the low-frequency conditions generally were found to be less than those for the high-frequency conditions. The fact that subjects were learning to perform the complex coordinator is displayed in the first three test trials. However, since an asymptotic level of response occurs for the last three test trials, the behavior for the last three trials could be described in terms of performance. Due to the variability of responses between noise level conditions for any of the last three test trials, it is difficult to assess the noise effects. Generally, on trials 4 and 5, performance was worse for the noise groups than for the ambient group. On trial 6, all groups were approximately at the same level of performance, although it appears that the noise groups might have continued to improve more than the ambient group if more trials had been presented. Overall, performance was worse for the high-frequency condition across all trials except trial 4. Findings of other studies support these results (refs. 5 to 11).

Effects of sex.- The analysis of variance in Table II indicated the main effect for sex as well as the sex x trials interaction was significant. The sex x trials interaction is illustrated in figure 3. As can be seen in this figure, females took longer to complete each trial than did the males. The significant interaction does not reduce the importance of the main effect. Evidence of the interaction may indicate a different rate of learning for this task for the males and females. An exact meaning of the sex differences is not known. Data on differences between the sexes in reaching asymptotic performance on the complex coordinator are not available. However, it is known that a

minimum of 6 hours of practice is required to establish steady-state performance for males (ref. 12).

Some information about the sex differences can be obtained from figure 4 which displays the response variance associated with the interaction of sex x noise x trials. The difference between sexes is most noticeable from comparing the responses of the females with those of the males for the high-frequency noise conditions. The sex difference can be in part attributed to the differential response of the two sexes to noise frequency characteristics. However, because these effects are confounded with a learning effect, more extensive research is needed to clarify each separate effect.

Annoyance Responses

The relationship between the annoyance ratings and noise frequency can be seen in figure 5. There is an increasing monotonic relationship between the annoyance ratings and noise frequency through 4,000 Hz. The annoyance ratings of the low- and high-frequency sounds (same sounds used in the performance tests) are also included in figure 5. These annoyance responses fall within the standard deviation ranges of the corresponding 125 Hz noise and the 4,000 Hz noise. These results are essentially in agreement with previous research (ref. 13). An analysis of variance of the annoyance ratings displayed no sex difference for this type of response. Similar results were obtained by reference 14.

Comparison Between Performance and Annoyance

Although there was a greater decrement in female performance for the high-frequency noise condition than for the low-frequency noise condition, the performance of the males for these noise conditions was generally the reverse.

However, it was found that for both males and females the high-frequency noises were the most annoying. Thus, a simple transformation between these response measures is not possible. A further implication is that both types of responses (performance and annoyance) may be needed in certain situations to adequately describe human reaction to noise.

CONCLUDING REMARKS

An experiment was conducted to investigate the effects of noise on performance and annoyance. Sixty subjects performed a complex psychomotor task while listening to either high-frequency noise, low-frequency noise, or ambient noise to determine the effects on performance. Upon completion of the task, annoyance ratings of various frequencies (63 to 8,000 Hz) were made by each subject using the method of magnitude estimation.

The results of the present study suggest that high-frequency noise detrimentally affects female performance, but it does not seem to affect male performance. However, the possible confounding effects of learning and of sex differences in ambient conditions make these results tentative. Contrasted to these performance effects, the sexes did not differ in their annoyance ratings. Thus, the implication was derived that there is not a simple transformation between performance and annoyance responses. A monotonically increasing relationship between annoyance and noise frequency was found (except for a decrease in annoyance at 8,000 Hz). Therefore, it is concluded that both performance and annoyance responses may need to be assessed in certain situations to adequately describe human reaction to noise.

APPENDIX A

SUBJECTS' INSTRUCTIONS FOR THE OPERATION OF THE COMPLEX COORDINATOR

In front of you is the complex coordinator apparatus. Reach out with your left hand and grasp the left control stick. Move it forward and backward a few times. (Pause) Now move the stick until the moving light is aligned with the light in the next column and hold it there. ("That's right" or repeat above.) This is a correct match for the left arm when the two lights are lit as they are now. Now take your hand away. A correct response is made for this machine when the four matching pairs of lights are on by simultaneously moving the two sticks with your hands and the two floor pedals with your feet until all four lights are matched to the colored problem lights in the next column, just as you did with your left hand. Let me repeat: when the four lights are on, match each problem light. If for instance you are to match the top light, the correct answer would be the top light. When you have correctly matched all four sets of lights, a new problem will automatically appear. Wiggle the controls if two response lights are on simultaneously in any one set. When the red light comes on, begin. Work for approximately 5 minutes until the light goes off. Rest until the light goes on again, at which time, work as before. Keep the earphones on at all times. Work as rapidly as you can. Any questions?

APPENDIX B

SUBJECTS' INSTRUCTIONS FOR THE ANNOYANCE RATINGS

You are going to be presented a series of sounds. Before each sound, a standard sound will be presented. The annoyance level (how bothersome it is) of this standard is 100. You are to tell me what number you would assign to each sound in comparison with the standard. In other words, you are to tell me how annoying you think each sound is in comparison to the standard. Try to give the appropriate number to each sound regardless of what you may have called the previous sound. If, for example, the sound seems twice as annoying as the standard, say 200. If it sounds one-fourth, say 25. As you know, there are infinite numbers above as well as below 100. You may use decimals, fractions, or whole numbers. Please rate the sounds according to how annoying (i.e., irritating, bothersome) they are to you compared to the standard. The standard will be presented before each sound. Verbally rate this sound compared to the standard during the blank space following each sound. You may observe a few long blank spaces. There will be more sounds presented following the long spaces. Remember the standard of 100 is presented before each sound. Are there any questions? Then we will begin. The first sound you will hear will be the standard with the annoyance level of 100.

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TABLE I.- EXPERIMENTAL DESIGN OF PERFORMANCE TESTS*

Noise Characteristics	Sex	Test Trials					
		1	2	3	4	5	6
High Frequency	Female (n = 10)						
	Male (n = 10)						
Low Frequency	Female (n = 10)						
	Male (n = 10)						
Ambient Noise	Female (n = 10)						
	Male (n = 10)						

*Time and error measures were separately analyzed as dependent performance response measures: Time = time to complete a trial, second; Error = number of overshoots per trial.

TABLE II.- ANALYSIS OF VARIANCE SUMMARY TABLE FOR PERFORMANCE TIME DATA

Source	Sum of squares	Degree of freedom	Mean square	F	Probability
Between subjects	1,225,097.7	59			
Sex	109,482.817	1	109,482.817	5.617	0.021*
Noise	8,654.412	2	4,327.206	0.222	
Sex x noise	54,516.934	2	27,258.457	1.399	
Subj. w. groups	1,052,443.5	54	19,489.694		
Source	Sum of squares	Degree of freedom	Mean square	F	Probability
Within subjects	1,622,964.1	300			
Trials	2,099,401.0	5	419,880.20	28.526	0.001*
Sex x trials	145,902.62	5	29,180.524	1.997	0.095*
Noise x trials	329,678.53	10	32,967.853	1.915	0.052*
Sex x noise x trials	332,965.34	10	33,296.533	2.163	0.026*
Trials x subj. with groups	3,715,016.60	270	13,759.321		
Total	7,848,061.8	359			

*Significant at the 0.1 level. The p-value of 0.1 was chosen because of the conservativeness of the analysis of variance computer program used.

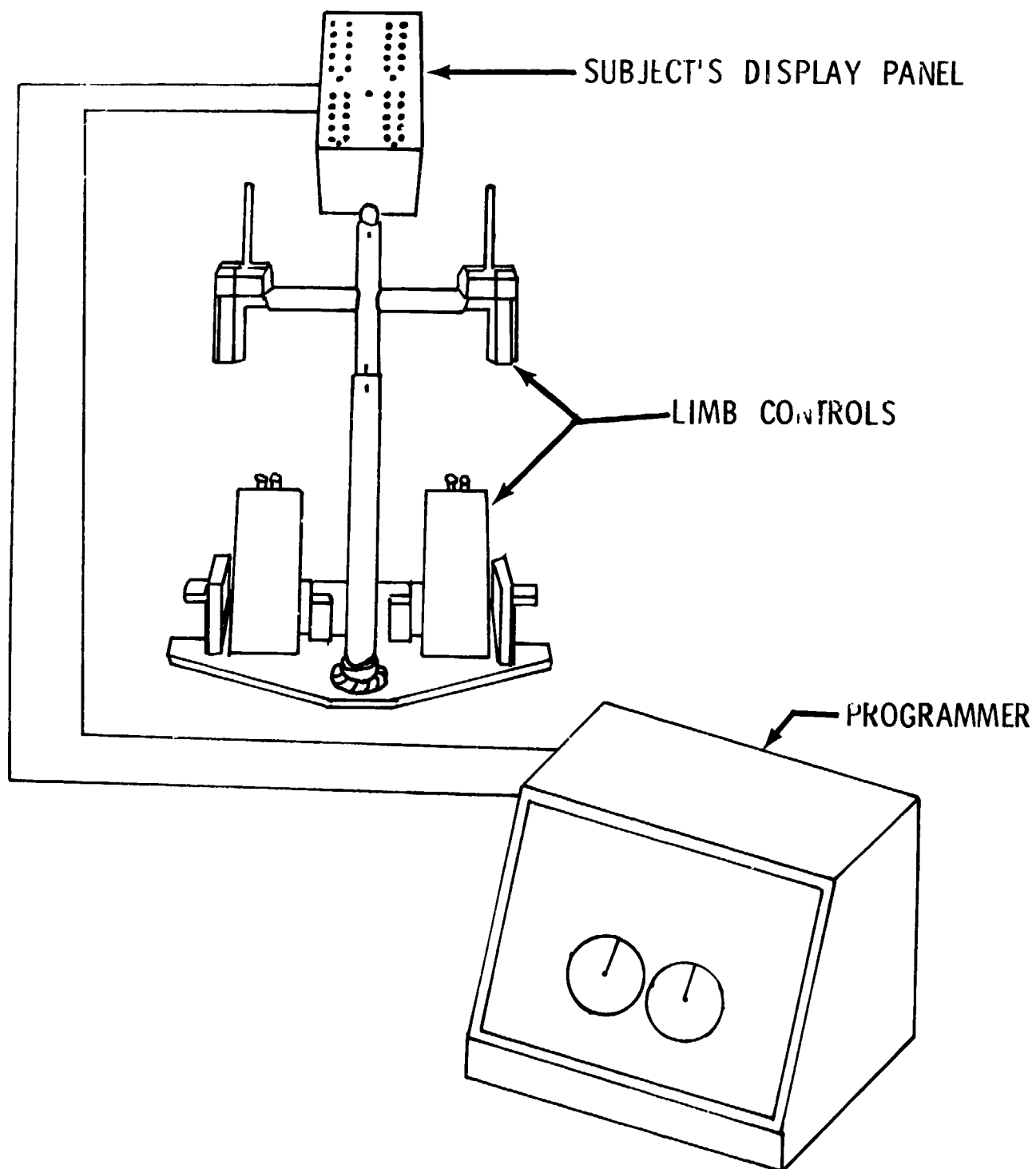


Figure 1.- Complex coordinator performance apparatus.

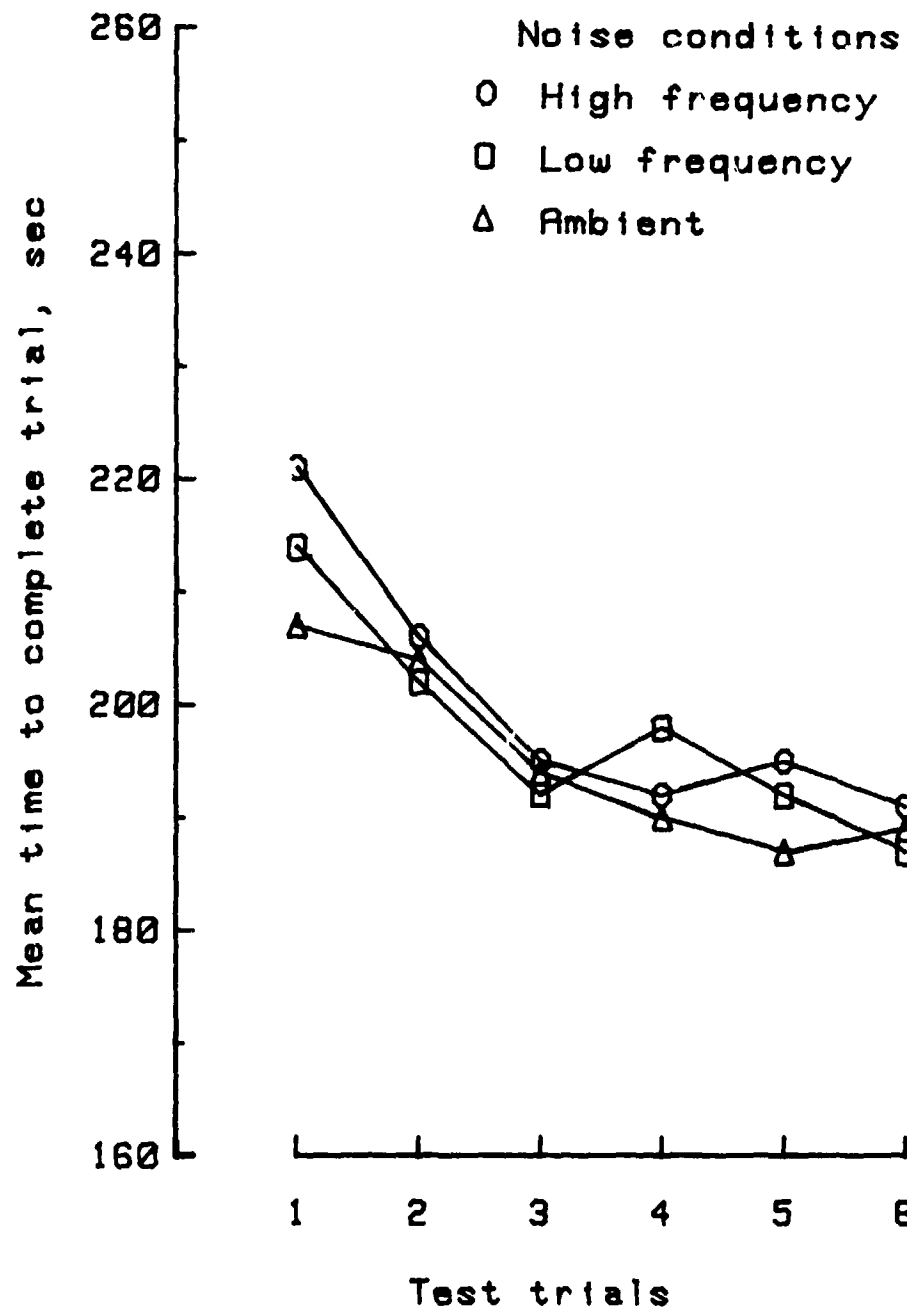


Figure 2.- Effects of noise and trials on performance.

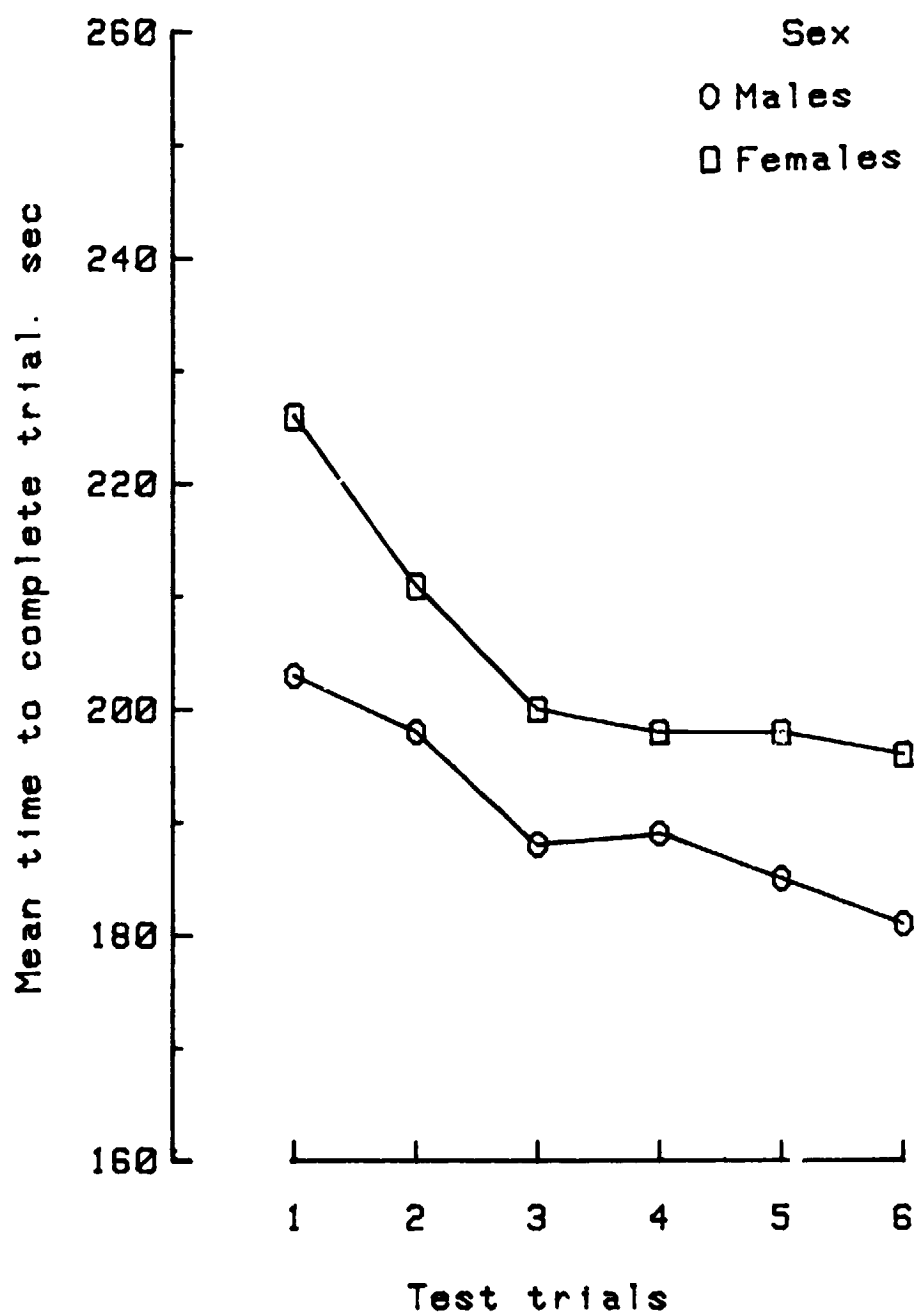
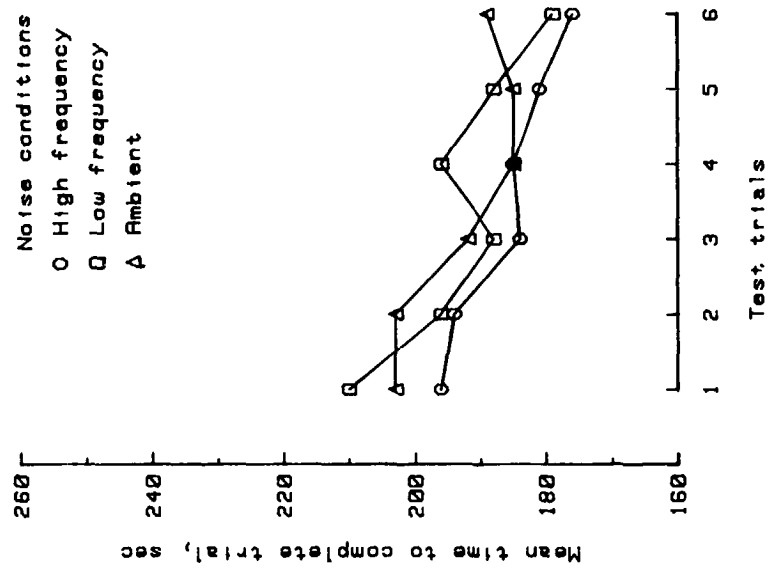
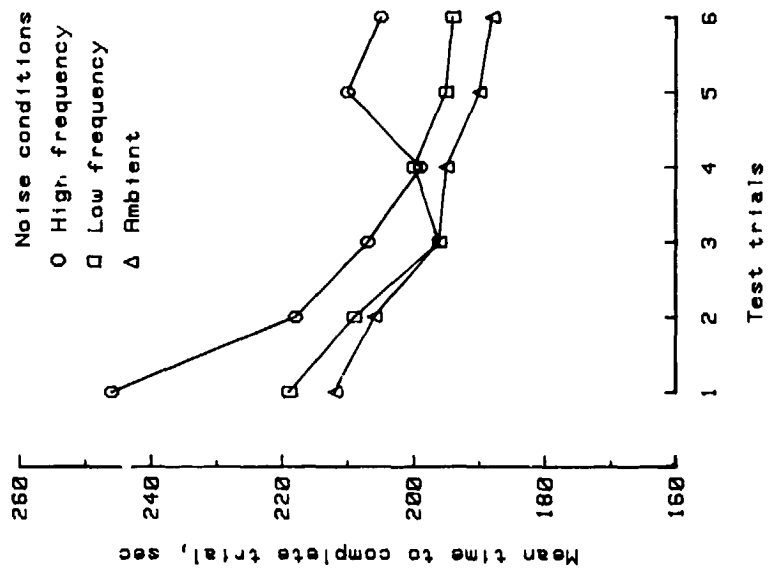


Figure 3.- Comparative female and male performance.



(a) Females



(b) Males

Figure 4.- Effects of noise and trials on performance for females and males.

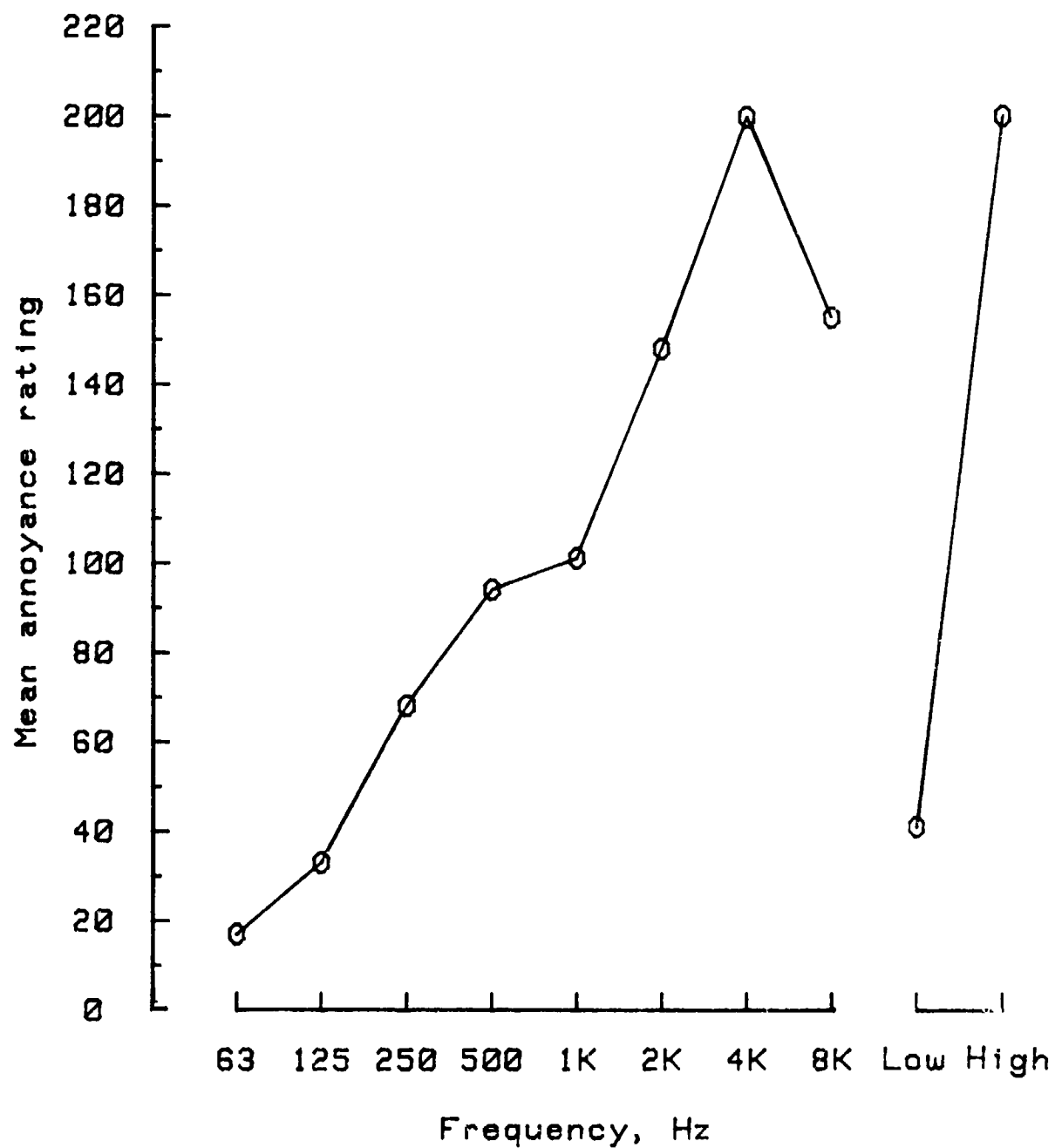


Figure 5.- Effects of noise frequency on annoyance.